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GROUND-BASED CORONAGRAPHIC OBSERVATIONS OF SOLAR STREAMERS

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ABSTRACT

The purpose of this paper is two-fold: first, to demonstrate that ground-based coronagraphs *can* observe coronal streamers and, secondly, to give examples of the type of streamer properties that can be deduced from such observations. This paper will not discuss eclipse or balloon-borne observations. The former will be discussed by another paper in this volume, and the latter are more properly discussed with respect to space-borne observations. Here, emission-line and white-light (K-coronagraph) observations relating to streamer electron density, magnetic field and polarization, population, intensity, large-scale organization, rotation, temperature and periodicities are included. This paper will not be an exhaustive review of all known papers in this field but will only use selected papers to demonstrate the types of work that can be done.

1. ARE THERE ANY GROUND-BASED CORONAGRAPHIC STREAMER OBSERVATIONS?

Due to the limited height-range of ground-based coronagraphs (GBCs), which is caused by scattering within the Earth's atmosphere of light from the solar disk, and the extreme height-range of streamers, which may extend out to and beyond the orbit of Earth, there is some skepticism that GBC observations can be shown to refer to streamers. For example, R. Smartt (private communication) believes that loops at the limb seen up to about r = 1.3 $R_\odot$ (0.3 $R_\odot$ above the limb) may not be the lower loops of helmet streamers. Additionally, Koutchmy et al. (Ref. 1) express doubt that inner coronal enhancements observed by GBCs refer to streamers. However, their paper does not give any basis for this statement. It should be noted that the appearance of the base of a streamer in a GBC would be only that of closed loops, as noted by the authors. Koutchmy and Livshits (Ref. 6) note that the open part of streamers begins at about 3 $R_\odot$.

On the other hand, many authors state without proof that they are studying streamers in both L (emission-line) and K (broad-band-white-light) observations. They apparently believe that it is self-evident.

Moving to studies containing some evidence for streamer observations, McKenzie (Ref. 2 and private communication) states that the maximum height of x-ray loops in non-flaring active regions is about r = 1.10 $R_\odot$. Perhaps this implies that higher loops are connected with streamers. I would also note that since streamers are large-scale structures they should be observable with existing low-resolution photoelectric GBCs; e.g., the 1.1′-resolution Emission-Line Coronal Photometer (ELCP) at the Sacramento Peak site of the U. S. National Solar Observatory (NSO/SP) (Fisher, Ref. 3; Smartt, Ref. 4). Attempting to further define the signature of streamers in GBC systems, Fisher and Sime (Ref. 31) discuss observations made with the K-Coronameter series of instruments at the Mauna Loa Solar Observatory (MLSO) of the High Altitude Observatory made since 1965 at 1.3 and 1.5 $R_\odot$. They define streamers in that record as local maxima in polarization brightness (pB) with FWHM > 9° in latitude and longitude, on the basis of their experience with the observations and previous comparisons of K-Coronameter data with eclipse and other images of the corona. Hansen et al. (Ref. 5) studied the time variation of the K corona with the MLSO K-Coronameter from 1964-67. They demonstrated that the long-term variation of pB is essentially identical at all heights from 1.125 to 1.75 $R_\odot$, which indicates that they observed the same structures (streamers) at all heights. They also demonstrated the rush-to-the-poles phenomenon at 1.125 $R_\odot$, which was first observed in polar-crown prominences. As noted by Koutchmy et al. (Ref. 1), this coronal feature certainly represents helmet streamers above the prominences. Koutchmy and Livshits (Ref. 6) note that the formation temperatures of Fe X and Fe XIV seen at the base of streamers are consistent with hydrostatic temperatures deduced in streamers of 1.3 to 1.6 MK. Smartt and Zhang (Ref. 7) in their Figure 1 show temperature differentiations in Fe X and Fe XIV around a prominence that certainly represent the lowest manifestations of the corona at the bottom of a streamer. Many authors intercompare eclipse and near-eclipse observations to prove that they are observing streamers with GBCs. Rusin and Rybansky (Ref. 8) state that for the corona during the 1980 eclipse, "it is difficult to find a place where no streamer was observed." Thus, GBC observations during at least that period would almost always be studying streamers. A similar situation existed at the 1990 and 1991 eclipses, as reported by Markova et al. (Ref. 9) and Rusin et al. (Ref. 10), respectively. Dollfus and Martres (Ref. 11) discuss observations at Pic-du-Midi with the K-Coronameter at 1.09 $R_\odot$. They observed several features elongated in the longitudinal direction that must certainly be streamers and conclude that this morphology is frequent, if not systematic, above quiescent prominences. A sketch is given in their Figure 9. A comparison of 1.3 $R_\odot$ MLSO K-Coronameter and 1.15 $R_\odot$ NSO/SP ELCP synoptic maps as given in Sime, Fisher and Altrock (Ref. 12) shows that most of the local enhancements in the emission lines are features that would be identified as streamers in the K-coronal record. Thus, it appears that there are several mechanisms for identifying coronal low-altitude features as being the low-altitude manifestations of streamers.

In the following sections several examples of inference of physical properties of streamers from GBC observations are presented.

2. ELECTRON DENSITY

Hansen et al. (Ref. 5) show in their Figure 14 streamer electron densities obtained with the MLSO K-Coronameter out to 2.0 $R_\odot$. Dollfus and Martres (Ref. 11) discuss the evolution of several streamers as observed at Pic-du-Midi with the K-

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Coronameter at 1.09 $R_\odot$. Their Figure 6 gives the density profiles. Munro and Fisher (Ref. 21) studied streamers as observed with the MLSO K-Coronameter at 1.3 $R_\odot$ and concluded that, at that height, they are 3.1 times denser than the Allen Minimum Model. Dollfus, Laffineur and Mouradian (Ref. 13) give an example of the comparison of near-eclipse observations of streamers at Pic-du-Midi and Meudon with eclipse observations (their Figure 8). This allows an intercalibration of the eclipse and near-eclipse intensities to be made. They further use the near-eclipse observations to locate the longitudes of streamers seen at eclipse time (their Figures 9 and 10). This allows a determination of whether the eclipse observations can be used for a reliable determination of the density of the observed streamers. Bagenal and Gibson (Ref. 14) studied the structure of a streamer as observed on 26 May 1986 by the MLSO K-Coronameter out to 2.3 $R_\odot$. By using the Bogdan and Low (Ref. 15) magnetostatic model and including polar currents, they obtained the electron density configuration as shown in their Figure 11 that produced the observed intensity distribution.

3. MAGNETIC FIELD AND POLARIZATION

Bagenal and Gibson (Ref. 14) also obtained the magnetic field configuration of a streamer as shown in their Figure 11. In Koutchmy et al. (Ref. 1), oscillations in a "coronal arch" (streamer base?) observed by Koutchmy (Ref. 16) and Koutchmy et al. (Ref. 17) are attributed to Alfven waves. Arnaud (Ref. 18) and Arnaud and Newkirk (Ref. 19) discuss the polarization in Fe XIV 5303Å and Fe XIII 10747Å, respectively. In Ref. 18, Fe XIV was observed at Pic-du-Midi with 1.0′ resolution between 1.1 and 2.0 $R_\odot$. Its average polarization is 1.6%, with a maximum of 10%. The polarized intensity pI has a mean value of 0.07 and a maximum value of 0.54 millionths. The direction of polarization is perpendicular to the limb with a FWHM of about 50°. His Figure 5 shows a sample map. In Ref. 19, Fe XIII was observed at NSO/SP with the Coronal Emission Line Polarimeter (KELP, not to be confused with the ELCP). Their Figure 2 shows an interpretation of the field structures responsible for the observed polarization out to 1.65 $R_\odot$ at 1′ resolution on an unspecified day. Several streamer-like features are present.

4. POPULATION

Fisher and Sime (Ref. 31) note that K-Coronameter observations at the limb cover 2 - 3 days (26 - 40°) of rotation. They calculate annual averages of the number of streamers per rotation from 1965-86. The number varies in phase with the sunspot number and is between approximately 6 and 14. They also find that the number of streamers may be equal to the number of streamer-destroying CMEs. Munro and Fisher (Ref. 21) find from a study of the morphology of K-Coronameter streamers on synoptic maps that streamers form much more rapidly than they decay.

5. INTENSITY

Altrock (Ref. 20) presented a new source of data on the solar output, namely "limb flux" from the one- and two-million degree corona. This parameter is derived from data obtained at NSO/SP with the 40-cm coronagraph of the John W. Evans Solar Facility and the ELCP. The limb flux is defined to be the latitude-averaged intensity in millionths of the brightness of disk center from an annulus of width 1.1′ centered at 1.15 $R_\odot$, of emission from lines at 6374Å (Fe X) or 5303Å (Fe XIV). The major source of intensity in these lines is from streamers, so this study may be thought of as referring to the flux of streamers vs. time. Fe XIV data have been obtained since 1973 and Fe X since 1984. Examination of the Fe XIV data shows that there is ambiguity in the definition of the last two solar-cycle streamer flux minima, which can affect the determination of cycle rise times and lengths. There is an indication that a constant minimum or basal corona, which may reflect the corona in the absence of all streamers, exists at solar minimum. Cycle 21 streamer flux was characterized in Fe XIV by 4 major thrusts or bursts of activity, each lasting on the order of a year and all having similar maximum fluxes, which indicates that coronal streamer flux is sustained over periods in which the sunspot number declines significantly. Dramatic increases in the fluxes occur from minimum to maximum, ranging from factors of 14 to 21 in the two lines. Fisher and Sime (Ref. 31) consider the causes of the solar-cycle variation of integrated K-Coronameter streamer brightness, previously calculated by them to be a factor of two. The variation in number of streamers with time accounts for half the variation; the other half is accounted for by the variation of polar coronal holes.

6. LARGE-SCALE ORGANIZATION

Altrock (Ref. 22) and Wilson et al. (Ref. 23) found that investigation of the behavior of Fe XIV 5303Å emission at 1.15 $R_\odot$ obtained at NSO/SP with the ELCP from 1973 to 1987 resulted in the confirmation of a second set of zones of coronal streamers at high latitudes that had been seen by earlier coronal observers, separate from those above the Main Activity Zones (MAZ). Localized emission maxima (streamers) are observed through most of the cycle at high latitudes in individual daily scans, annual averages, and a solar-cycle summary plot of the location of all local intensity maxima ("butterfly diagram"). These maxima evolve slowly over a period of days, consistent with the rotation over the limb of stable streamers, in a manner similar to that of the lower-latitude streamers that are connected with active regions. The high-latitude streamer zones first appear at latitudes of 70 to 80°, 2-3 years after solar minimum. They evolve approximately parallel to the MAZ, with the average latitude decreasing at a rate of roughly 5-6° per year. After their appearance, they are present more or less continuously until the following solar minimum. Near solar minimum, the high-latitude streamer zones that appeared after the beginning of Cycle 21 monotonically evolved into the streamer zones over the MAZ of Cycle 22. It thus appears that we have evidence from these streamer observations for parallel, overlapping, extended solar cycles (ESCs) that begin every 11 years but last approximately 18-20 years. Fisher and Sime (Ref. 31) calculate the variation with latitude of K-Coronameter streamers averaged over 1965-86: streamers occur at all latitudes and maximize at ±20°. They also display the annual organization of streamers with latitude and longitude. In 1975, streamers appeared mainly over the magnetic neutral sheet. In 1981 there was no organization: half of the streamers were associated with active regions and high-latitude filaments. In addition, they display a streamer "butterfly diagram" that has only slight evidence for the ESC. This may be due to the different height of observation (different scale-size [spatial wavenumber] sensitivity) and different integration path length at the limb relative to the ELCP observations. Munro and Fisher (Ref. 21) caution that, due to evolution, the peak brightness of a streamer as it crosses the limb does not necessarily yield the correct inference of the longitude of the streamer base.

7. ROTATION RATE

Sime, Fisher and Altrock (Ref. 24) studied the rotation of the Fe XIV corona at 1.15 R with the NSO/SP ELCP and related it to an earlier study (Fisher and Sime, Ref. 25) of rotation of the K corona as observed with the MLSO K-Coronameter. The auto-correlation technique utilized in both studies accentuates the rotation of bright features, which are primarily streamers. The average differential rotation rates from 1973 to 1985 are shown in their Figure 9 and the annual variation of these rates are shown in their Figure 8. Examination of the average synodic rotation period as a function of latitude for this interval shows that, as is the case for the white-light corona, on average the Fe XIV corona rotates more rigidly than do features in the photosphere or chromosphere. However, there is a significant and strongly-time-varying component that shows differential rotation. This component appears during cycle 21 at high (> 60 degrees) latitudes in the late ascending phase and moves toward the equator, similar to the ESC. As the cycle progresses, this component becomes indistinguishable from faster rotating features near the equator, and the effect is to produce a net differential rotation that is intermediate between those of the photosphere and the white-light corona.

8. TEMPERATURE

Dollfus (Ref. 26) describes observations of streamers in white light, Fe X, Fe XIV, Ni XV (6702Å) and Ca XV made with a full-limb coronagraph at Pic-du-Midi. He does not justify the assertion that he is observing streamers as opposed to low-level loops unconnected to streamers. He finds that streamers are not always visible in both white light and Fe XIV. Furthermore, streamers observed in all five wavelengths show complex relationships resulting from lateral temperature gradients in the streamers. In these examples, the streamer may be visible in two or more bandpasses with differing morphology (cf. his Figures 5 and 6). He also gives examples of temporal evolution of temperature structure. He concludes that rapid variations of the visibility of structures result from rapid variations in the exciting mechanism; however, I wonder if this may be due to visibility variations due to sky fluctuations. Guhathakurta et al. (Ref. 27) use NSO/SP ELCP data to calculate the temperature of the corona at the time of the March 18, 1988, solar eclipse. They demonstrate that the plasma temperature can be derived unambiguously from the intensity ratio of Fe XIV/Fe X. They find that the temperature derived in this manner increases from a background level of approximately 1.3 MK by 15% or more in streamers at 1.15 $R_{\odot}$.

9. PERIODICITIES

Altrock, Radick and Henry (Ref. 28) reported on a search for non-rotational periodicities in solar Fe XIV and Fe X flux during solar cycles 21 and 22. They used sixteen years of Fe XIV 5303Å data and six years of Fe X 6374Å data obtained with the NSO/SP ELCP. Absolute intensities were recorded daily and averaged over latitude at the East limb, West limb or the entire limb, to produce the flux from (sections of) an annulus 1.1′ wide centered on 1.15 $R_{\odot}$. Since such fluxes are mainly sensitive to the high intensities encountered in streamers, the results refer mainly to the temporal variation of streamers. These fluxes were analyzed by two independent methods. The daily values were analyzed by the modified periodogram technique (Scargle, Ref. 29; Radick et al., Ref. 30). In addition, 27-day-average values were analyzed by the autocorrelation technique. Persistent signals were seen at periods near one year in both ions. These signals were identified in Fe XIV as being due to surges of activity about every year during the maximum phase of cycle 21. Persistent signals were seen at periods near 7-10 months in both ions. Periods in this range have been identified in a number of other data sets. Periods near 155 days were observed in Fe XIV during the maximum phase of cycle 21 and in Fe X from 1984 onwards. Oscillations in the Fe X flux are clearly seen over the last two years, a result that was not expected. No persistent signals were seen at a period of 51 days. The periodogram technique appears to be a powerful method for analyzing the time variation of power as a function of frequency. However, the identification of ridges in the periodogram technique is sensitive to the length of the sliding window. Rotational signals are clearly seen in both techniques but were not investigated in this study.

10. GROUND-BASED OBSERVATIONS VS. SOHO OBSERVATIONS

Table 1 compares the best capabilities of GBC observations vs. the current parameters of the LASCO C1 coronagraph, to which the GBCs are best compared. The parameters considered are the minimum observable height, the spatial resolution and the maximum observable intensity in millionths of the brightness of the center of the disk. Of course, the C1 coronagraph will not be affected by seeing or atmospheric background, as are GBCs. The optical quality of C1 and GBCs may be similar, assuming that no disruption of C1 occurs during launch.

Table 1: SOHO LASCO C1 vs. ground-based coronagraphs.

	LASCO C1	Ground-Based
h_{min} ($R_{\odot}$)	1.1	1.005-1.015
resolution (")	5.6	<1
I_{max} (millionths)	20	>100

GBCs will nicely compliment C1. They will be able to observe higher intensities and closer to the limb with better spatial resolution. In addition, comparison between C1 and GBCs will aid in intensity calibration and determination of scattered light and other noise sources of both C1 and GBCs, as well as the determination of the effect of atmospheric scattered light on GBC observations.

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